METHOD FOR NAVIGATING IN THE INTERIOR OF A BODY USING

THREE-DIMENSIONALLY VISUALIZED STRUCTURES

5   The invention relates to a method for navigating, for
example a surgical instrument or an endoscope, in the
interior of the body using three-dimensionally visualized
structures.

10   During surgical operations, an attempt is made, as a rule,
to make as small a cut as possible through the skin of the
patient. Said cut is often just big enough in order to be
able to reach the anatomical structure to be treated in the
interior of the body with surgical instruments. For this
15   reason, it is difficult for the surgeon and often even
impossible to survey optically those anatomical structures
of the patient that are relevant to the operation. Even the
position, for example, of surgical instruments relative to
an anatomical object to be treated is often not visible to
20   the surgeon. For this reason, methods of visualizing
structures in the interior of the body for the purpose of
navigating such instruments are increasingly gaining in
importance.

25   DE 198 07 884 A1 describes a method for navigating a
surgical instrument in the interior of the body. In
accordance with this method, a plurality of images are made
from various positions and orientations by means of an
imaging device and the relative positions and orientations
30   of the images with respect to one another are determined.
Then, with the aid of said images, the relative position of
an anatomical target object with respect to the surgical
instrument is intraoperatively determined and visualized.

Both for the precise planning of an operation and for the
optical monitoring of the course of the operation, two-
dimensional images, such as X-ray images, are as a rule
5   inadequate. There is therefore a requirement to use three-
dimensional representations.

Such three-dimensional representations can be generated,
for example, by means of computer tomography (CT). Because
10   of the equipment factors and because of the high
computational expenditure, CT methods are primarily used to
obtain preoperative data. CT methods are therefore
unsuitable for an intraoperative visualization, i.e. a
visualization taking place during the operation.
15   Furthermore, the high radiation exposure accompanying the
CT methods is in many cases undesirable for the patient.

To avoid high radiation exposure, thought can be given to
generating the three-dimensional representations needed to
20   plan the operation and to monitor the course of the
operation from two or more two-dimensional representations.
Such a method is described, for example, in US 4,899,318.

The object of the invention is to provide a method for
25   navigating using three-dimensionally visualized structures
in the interior of the body, which method avoids high
exposures of the patient to radiation, is associated with
low computational expenditure and is therefore suitable, in
particular, also for intraoperative use.
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According to the invention, this object is achieved in
that, in a first step, at least two two-dimensional images

of the same anatomical object from different perspectives
and also of information about the respective spatial
position of the imaging system relative to the anatomical
object are provided. In a second step, a projection of at
5   least one geometrical structure to be visualized is then
defined in each of the two-dimensional images, wherein the
geometrical structure to be visualized is different from
the anatomical object. In a third step, a conical surface
is generated in space for each of the images, wherein the
10   spatial positions of cone vertex and cone directrix are
determined from the spatial position of the imaging system
and the shape of the cone directrix is determined from the
projection determined for the geometrical structure to be
visualized on the respective image. In a fourth step, the
15   spatial intersection of the individual conical surfaces is
formed, wherein said spatial intersection corresponds to
the geometrical structure to be visualized in the interior
of the body. Then the geometrical structure determined in
this way or an intersection of a plurality of geometrical
20   structures determined in this way or both the structures
and their intersection are represented graphically and the
representation is used for navigation.

Expediently, either the anatomical object or, for example,
25   a surgical instrument, or both, are also graphically
represented three-dimensionally as navigation aid in
addition to the geometrical navigation structure. The
three-dimensional representation of the anatomical object
and of the surgical instrument may, in this connection, be
30   obtained in the same way as or in a similar way to the
three-dimensional representation of the geometrical
structure.

In accordance with the present invention, a three-
dimensional model of the geometrical structure to be
visualized is consequently prepared from projections
5   created on the basis of a few two-dimensional images and
this model is used for navigation. Since, in the simplest
case, only two two-dimensional images have to be present
and these two images do not necessarily have to be prepared
by an image-forming method that uses X-ray radiation or
10   another high-energy radiation, the radiation exposure for
the patient is negligibly small in the visualization method
according to the invention compared with conventional CT
methods. Since, in addition, the amounts of data to be
processed are also relatively small, in particular,
15   compared with CT methods, the visualization can be
performed extremely rapidly and even intraoperatively in
order to provide the surgeon with actual information about
the course of the operation. Furthermore, the exposure to
radiation can be appreciably reduced for the OP team.
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The projections can be created on the basis of the images
in various ways, for example automatically, partially
automatically or manually. Expediently, the creation takes
place in such a way that, after the creation, information
25   relating to the created projections is available in the
form of digital data and can be further processed for the
purpose of visualization in a computer-aided manner.

The shape of the geometrical structure to be visualized is
30   simultaneously determined during the creation of the
projection of the geometrical structure on the basis of
individual images. The projection to be created in a

certain image may, for example, be a point, a straight
line, a circular segment or any other structure having the
form of a line. The geometrical structure to be visualized
may be any one-dimensional, two-dimensional or three-
dimensional structure, such as a point, a straight line, a
plane or a cone.

The geometrical structure to be visualized does not
correspond to the anatomical object imaged on the basis of
the two-dimensional image, but may be derived from it.
Thus, for example, a circular-segment projection may be
created in the region of the ball-shaped head of the femur
bone on the basis of an image of a femur bone in order to
visualize a navigation aid in the shape of a geometrical
sphere structure. Navigation using geometrical structures
visualized in this way has the advantage over navigation
using, for example, the femur bone or a model of the femur
bone in that it is simpler, clearer and, therefore, also
safer and more rapid. The operation time can therefore not
only be shortened by means of the navigation method
according to the invention, but also the operation safety
can be increased.

The determination of items of information that permit
conclusions to be drawn about the spatial positions of the
imaging system in which the image has been recorded may
take place in a variety of ways. Thus, for example, the
spatial position of the imaging system may be unalterable
and, as a rule, known in advance, and the position of the
anatomical object may be changed from image to image. The
associated imaginary perspective can then be calculated

back from the respective position of the anatomical object assuming a positionally fixed anatomical object.

On the other hand, it is also possible, and often even
5   expedient, to place the anatomical object in space in a positionally fixed manner and to alter the spatial position of the imaging system from image to image. To determine the respective spatial positions of the imaging system, a tracking system known from the prior art is preferably used
10   in this case. If an X-ray imaging system having a C-shaped support arm is used, a marker may be applied to the C-shaped support arm for an infrared tracking system installed in space. The precise spatial position of the C-shaped support arm, which permits a conclusion to be
15   drawn about the spatial position of an X-ray source and an X-ray detector, can then be determined by means of the tracking system. The spatial position of the X-ray source and of the X-ray detector determines the spatial position of the conical surface. Furthermore, the position of the C-
20   shaped support arm can be determined by using a positionally fixed robot. The robot moves a calibration object provided with marks impervious to X-rays in the beam path of the C-shaped support arm. From the position of the marks in the image, the position of the C-shaped support
25   arm can be calculated.

The individual two-dimensional images can be prepared in various ways. Depending on the imaging method, the spatial positions of the cone vertex and cone directrix are
30   determined in various ways. In the X-ray imaging method already mentioned and preferably used, the anatomical object and, if applicable, also the surgical instrument are

disposed between an X-ray source and an X-ray detector. In
the simplest case, the spatial position of the X-ray source
corresponds to the spatial position of the cone vertex and
the spatial position of the X-ray detector to the spatial

5   position of the cone directrix. If X-ray optics are used,
the spatial positions of the cone vertex and cone directrix
can be calculated back from the characteristic data of the
X-ray optics. Even if the two-dimensional images have been
prepared by image-forming methods other than X-ray methods

10   (infrared methods, ultrasonic methods, MR methods, etc.),
it is necessary, as a rule, to take account of the
respective system parameters of the imaging system in
addition in the determination of the spatial position of
the cone vertex and cone directrix.

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Advantageously, a conical surface is generated in space for
every two-dimensional image. A conical surface is produced
by moving a straight line that passes through a fixed
point, the cone vertex, along a curve, the cone directrix.

20   The cone directrix consequently determines the shape of the
conical surface.

The cone directrix may be a straight line that is created,
for example, as the preferred direction desired by the

25   surgeon in the individual images. The preferred direction
may characterize that direction from which, for example, an
endoscope or a surgical instrument is to approach an
anatomical object to be treated. If the cone directrix is a
straight line, the associated conical surface has a

30   triangular shape.

In the extreme case, the cone directrix may also be a point
that is created, for example, as target position in each of
the images. Said target position may characterize a place
at which a surgical intervention is to take place. In the
5   case of a punctiform cone directrix, the associated conical
surface has the shape of a straight line.

In contrast to the three-dimensional visualization of an
anatomical object, such as a femur bone, which can take
10   place only approximately using only two images (see Figure
4), a preferred direction to be visualized or a sphere to
be visualized can be created precisely and unambiguously by
means of two images, i.e. by means of the intersection of
two cones.

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In accordance with a preferred embodiment of the invention
that may be used regardless of the visualization of the
geometrical structure, at least one further data set that
has been prepared preoperatively or intraoperatively can be
20   used for the refining correction of, for example, an
approximation model of an anatomical object after the
formation of the spatial intersection of individual conical
surfaces. Said further data set may be a data set prepared
by a magnetoresonance method (MR method). MR tomography has
25   the advantage that it is not associated with any exposure
of the patient to radiation. It may, for example, refine a
three-dimensional representation of an anatomical object
generated from two-dimensional X-ray images by means of one
or more MR images. Conversely, it is possible, with the aid
30   of additionally recorded X-ray images, to refine a three-
dimensional representation of the anatomical object
generated from two-dimensional MR images.

Thus, for example, thought may be given to providing at
least two two-dimensional X-ray images of the same bone
from different perspectives that permit conclusions to be
5   drawn about the respective spatial position of the X-ray
imaging system relative to the bone and also an MR data set
of the bone. A projection can then be created of a surface
or of an outline of the spongiosa of the bone in every two-
dimensional X-ray image and a conical surface in space can
10   be generated for every X-ray image, the spatial position of
cone vertex and cone directrix being determined from the
respective spatial position of the imaging system and the
shape of the cone directrix can be determined from the
shape of the projection. To determine a first model of the
15   surface of the spongiosa, a spatial intersection can be
formed of the individual conical surfaces and a second
model of the spongiosa can be determined from the MR data
set. A representation of the bone can then be generated by
combining the two models, it being possible, for example,
20   to navigate using the representation. The first three-
dimensional model can also be determined in another way as
explained above.

The geometrical structure resulting from the spatial
25   intersection of the conical surfaces or an approximation
model of the anatomical object may be corrected by a data
set which is such that it contains a generic, shape-
variable model of the structure or of the object. Such a
generic model can be derived, for example, from anatomical
30   atlases or from an exact model of a patient comparable
according to age, sex, origin etc.

In accordance with a further aspect of the invention, after
the calculation of a three-dimensional representation, for
example, of a geometrical structure, of an anatomical
object or of a surgical instrument, an inverse calculation
5   may be made in order to determine suitable spatial
positions of the imaging system for further two-dimensional
images in order to improve the representation. Preferably,
these calculations may be performed intraoperatively and
still processed appropriately during the operation in order
10   gradually to refine the initial representation. Thus,
imaging directions may be indicated to the surgeon for the
C-shaped support arm of an X-ray imaging system from which
a fluoroscopy appears expedient on the basis of previous
calculations.

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In the case of intraoperative visualization, the actual
position of an instrument to be navigated, such as a
surgical instrument, an endoscope, etc., is preferably
represented simultaneously in addition to the anatomical
20   structure to be treated. The position of the instrument
relative to the anatomical structure to be treated can be
determined in various ways. Thus, for example, the marker
of a tracking system may be applied to the instrument and
the actual position of the instrument determined with the
25   aid of the tracking system. On the other hand, it would
also be conceivable to determine the position of the
instrument with the aid of the visualization method
according to the invention. Preferably, in addition to the
instrument, the effective axis of the instrument is also
30   represented. The effective axis indicates for example, that
direction in which a surgical instrument is applied.

Furthermore, the actual spacing of the instrument from the anatomical object to be treated can also be indicated.

In addition to the geometrical structure to be visualized,
5   the individual two-dimensional images that underlie the visualization of the geometrical structure can also be represented graphically at the same time. The individual two-dimensional images can be arranged in the representation in such a way that their spatial position in
10   the graphical representation corresponds to their respective perspective.

In accordance with a further embodiment of the invention, a navigation aid may be formed for the instrument in the
15   above-described graphical representation of the geometrical structure to be visualized or in a separate representation. The navigation aid indicates for example, the actual position of the effective axis of the surgical instrument relative to a preferred direction to be visualized in the
20   form of a tunnel structure. The navigation aid may comprise, furthermore, directional arrows that facilitate the alignment of the effective axis along the preferred direction.

25   Further advantages and details of the invention emerge from the exemplary embodiments and the figures. In the figures:

Figure 1 shows a diagrammatic representation of a surgical
              intervention with the aid of a tracking system;
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Figure 2 shows a diagrammatic representation of a conical
              surface;

Figure 3 shows the determination of a model of a structure
          to be visualized with the aid of the spatial
          intersection of two conical surfaces;

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Figure 4 shows the navigation of a surgical instrument with
          the aid of the two-dimensional images and of the
          model of the structure to be visualized;

10   Figure 5 shows a two-dimensional sectional view of the
          spatial intersection of two conical surfaces;

Figure 6 shows a representation according to the invention
          of a surgical intervention on a viewing screen;

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Figure 7 shows a planned surgical intervention using a
          surgical drill;

Figure 8 shows two X-ray images for preparing the surgical
20   intervention in accordance with Figure 7;

Figure 9 shows the determination of a model of the
          structure to be visualized in accordance with
          Figure 7; and

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Figures 10 to 12 show a navigation aid according to the
          invention.

Figure 1 shows diagrammatically an operation scenario based
30   on the visualization method according to the invention.
      Disposed on an operating table 10 is an anatomical object
      to be treated operatively in the form of a femur bone 12.

The surgical intervention is performed with the aid of a
surgical instrument 14. Attached to the surgical instrument
14 is a marker 16 of an infrared tracking system. Said
marker 16 is designed to transmit infrared radiation. The
5   infrared tracking system comprises, furthermore, an
infrared detector 18 disposed in a positionally fixed
manner. A localization computer 20 of the tracking system
calculates the actual spatial position of the surgical
instrument 14 provided with the marker 16 from the signals
10   received by the infrared detector 18. The calculated
spatial co-ordinates are transmitted by the localization
computer 20 via a data bus to a central computer 22, where
they are processed graphically and represented graphically
on a viewing screen 24.

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Figure 1 shows, furthermore, an X-ray imaging system 26
having a C-shaped support arm 28. Disposed at one of the
two ends of the C-shaped support arm 28 is an X-ray source
30 and at the opposite end of the C-shaped arm 28 an X-ray
20   detector 32. The two-dimensional images prepared by the
X-ray imaging system 26 are fed via a data bus to the
central computer 22 in digitized form. At the same time,
the central computer 22 also serves to control the X-ray
imaging system 26.

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A plurality of two-dimensional images has already been
prepared in the run-up to the surgical intervention by the
X-ray imaging system 26 and processed according to the
invention in the central computer 22. In the X-ray imaging
30   system 26, the spatial position of the perspective is
determined by the spatial position of the X-ray source 30
and the spatial position of the image plane is determined

by the spatial position of the X-ray detector 32. To
determine the spatial position of X-ray source 30 and X-ray
detector 32, a further marker 34, whose structure
corresponds to the structure of the marker 16 disposed on
5   the surgical instrument 14, is attached to the C-shaped
support arm 28 of the X-ray imaging system 26.
Consequently, in addition to the spatial position of the
surgical instrument 14, the spatial position of the
perspective and the image plane can also be determined by
10   means of the infrared detector 18 of the infrared tracking
system. The relevant items of information are likewise made
available to the central computer 22 via the localization
computer 20.

15   The central computer 22 generates a three-dimensional
approximation model of the femur bone 12 from the
intraoperatively obtained two-dimensional images and
represents said approximation model, a geometrical
structure to be visualized and also the relative position
20   of the surgical instrument 14 with respect to the femur
bone 12 or to the geometrical structure, graphically on the
viewing screen 24.

The performance of the visualization method according to
25   the invention is explained in greater detail below with
reference to Figures 2 to 12.

Figure 2 shows a conical surface 40. Said conical surface
40 is produced by moving a straight line 42, which passes
30   through the cone vertex 46, along the cone directrix 44.
Proceeding from the vertex 46 of the cone, the conical

surface extends along the straight line 42 to infinity and
includes the directrix 44.

After the generation of a conical surface has been
5   explained by way of example in Figure 2, the three-
dimensional visualization by means of conical surfaces is
revealed by considering Figure 3. Figure 3 shows two
conical surfaces 40 and 40' in their relative spatial
arrangement with respect to one another. Furthermore,
10   Figure 3 shows two two-dimensional images 50, 50' that were
recorded by the X-ray imaging system 26 shown in Figure 1.
The spatial positions of the cone vertices 46, 46' of the
two cones 40, 40' are created by the spatial positions of
the X-ray source with respect to the recording time of the
15   two images 50, 50'. The shape of each cone directrix 44,
44' is determined by the particular outline of the femur
bone shown by way of example in the images 50, 50'. In
Figure 3, the two images 50, 50' are disposed in that
spatial position in which the respective image planes were
20   situated.

An approximation model 52 of the anatomical object in the
form of the femur bone 12 shown in the original in Figure 1
is obtained by forming the spatial intersection of the
25   conical surface 40 with the conical surface 40'.

As can be inferred from Figure 3, the approximation model
52 of the femur bone is still comparatively coarse. The
model 52 can be refined in that, in addition to the two
30   images 50, 50', yet further images of the femur bone 12 are
recorded from additional perspectives and the approximation

model is then determined on the basis of the spatial
intersection of three or more conical surfaces.

5   A further possibility for improving the approximation model
52 is to take account of a preoperatively determined MR
data set of the femur bone shown in Figure 1 in preparing
the approximation model 52. Specifically, a three-
dimensional model of the femur bone 12 can also be
calculated with the aid of MR tomography.

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A typical bone is made up of a soft core tissue (spongiosa)
that is enclosed by a thin layer of hard tissue
(corticalis). The thickness of the corticalis layer is
variable. Although the use of MR tomography is desirable,

15   the corticalis layer is very difficult to segment
automatically in MR images. However, both the edge of the
corticalis layer and the underlying edge of the spongiosa
are visible in the X-ray image. A basic problem in MR
tomography is therefore that only the spongiosa of the

20   femur bone is imaged with good visibility, whereas the
outer corticalis layer appears black. The three-dimensional
model obtained from the MR data set does not consequently
correspond to the actual shape of the femur bone 12 since
the outer corticalis layer is missing. Nevertheless, the MR

25   model makes it possible to draw conclusions about the shape
of the femur bone that can be used to refine the
approximation model 52 shown in Figure 3.

It is therefore possible to proceed as follows: the edge of

30   the spongiosa is marked in the X-ray image and the surface
of the spongiosa is automatically segmented in the nuclear
spin image. A method for overlapping the last two

structures (2D X-ray contours and 3D nuclear spin surface,
each in the case of the spongiosa) can then be used for the
registration step (spatial alignment of the position of the
nuclear spin image with the X-ray images). Thus, the actual
5   bone surface (with corticalis layer) can be visualized and
function as a basis for navigation.

Thought can also be given to marking the contour of the
spongiosa in the images 50, 50' shown in Figure 3 and
10 visualizing the spongiosa structure by the method according
to the invention. In this way, the precise spatial position
of the spongiosa structure can be determined. The shape of
the spongiosa structure can then be revised using the MR
data set.
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Figure 4 illustrates a two-dimensional section through the
spatial arrangement shown in Figure 3. The intersection
plane shown in Figure 4 contains the two cone vertices 46,
46' and also two straight lines 54, 56 that form the
20 boundary of the conical surface 40 and two straight lines
54', 56' that form the boundary of the conical surface 40'.
The region of the intersection of these four boundary
straight lines 54, 56, 54', 56' establishes that cross
section of the approximation model 52 that extends through
25 the plane shown in Figure 4.

Figure 4 likewise shows the actual circular cross section
of the femur bone 12. Consequently, the deviation of the
cross section of the approximation model 52 from the actual
30 cross section of the femur bone 12 can be inferred from
Figure 4. As is evident from Figure 4, the deviation of the
approximation model 52 from the actual shape of the femur

bone 12 is particularly severe at those points where the boundary straight lines 54, 56, 54', 56' intercept. This insight can be used to optimize the perspectives in regard to the position of the planned surgical intervention.

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Figure 5 shows diagrammatically a possible way of graphically representing intraoperatively the approximation model 52 determined by the above-described visualization method on the viewing screen 24 shown in Figure 1. In

10   addition to the approximation model 52, the actual position of the surgical instrument 14 relative to the approximation model 52 is also represented graphically. The actual position of the surgical instrument 14 is determined, as explained above, with the aid of the infrared tracking

15   system shown in Figure 1. To visualize the shape of the surgical instrument 14, recourse is made to a previously stored CAD data set.

In addition to the approximation model 52 and the surgical

20   instrument 14, three two-dimensional images 50, 50', 50" of the femur bone 12 are also shown on the viewing screen 24. Said images 50, 50', 50" have been prepared with the aid of the X-ray imaging system 26 shown in Figure 1. They are shown on the viewing screen 24 in regard to the

25   approximation model 52 in that spatial position in which the X-ray detector 32 was situated relative to the femur bone 12 during production of the respective image 50, 50', 50". This facilitates the navigation of the surgical instrument 14 for the surgeon. The images 50, 50', 50"

30   show, furthermore, the respective projections 60, 60', 60" of the effective axis of the surgical instrument 14.

Figure 6 shows a further possible way of intraoperatively
representing the course of an operation graphically in the
form of a viewing-screen printout. The representation in
accordance with Figure 6 substantially corresponds to the
representation in accordance with Figure 5. As a departure
from Figure 5, however, Figure 6 does not show a three-
dimensional approximation model of the entire femur bone,
but only a three-dimensional approximation model 64 of a
tumour that has attacked the femur bone. The three-
dimensional approximation model 64 of the tumour is based
on four two-dimensional images 50, 50', 50", 50''' of the
femur bone. The four images 50, 50', 50", 50''' are
graphically disposed in such a way that they reproduce that
respective position of the X-ray detector 32 relative to
the femur bone 12 in accordance with Figure 1 in which the
respective image 50, 50', 50", 50''' was prepared.

Each of the four images 50, 50', 50", 50''' contains a
graphical representation 62, 62', 62", 62''' of the tumour.
On the basis of the outlines of the four representations
62, 62', 62", 62''', four conical surfaces whose spatial
intersection corresponds to the three-dimensional
approximation model 64 of the tumour were generated, as
explained with reference to Figure 3.

The viewing-screen representation in accordance with Figure
6 shows, furthermore, two projections 66, 66' of the
approximation model 64 that additionally facilitate the
monitoring of the surgical intervention for the surgeon.
Furthermore, the spatial position of the surgical
instrument 14 relative to the approximation model 64 is
sketched in Figure 6. The corresponding projection of the

effective axis 60, 60', 60", 60''' of the surgical
instrument 14 is sketched in each of the four images 50,
50', 50", 50'''. This graphical measure also helps the
surgeon to monitor the surgical intervention
5   intraoperatively.

Whereas the removal of a tumour is sketched in Figure 6,
the surgical intervention of a drilling in the ball-shaped
head 70 of the femur bone 12 using a geometrical navigation
10 structure is described below with reference to Figure 7. In
such a drilling, the problem is that the surgical
instrument, namely the drill 14 illustrated in Figure 7 is
to be introduced into the femur bone 12 only down to a
certain penetration depth since the drill 14 must not
15 puncture a cartilage layer on the surface of the ball-
shaped head 70 of the femur bone 12. The drill 14, which is
to be introduced into the femur bone 12 in the position 72,
must consequently not penetrate the femur bone 12 to such
an extent that it reaches the puncture point 74.
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Although the cartilage layer is visible on the ball-shaped
head 70 of the femur bone 12 in X-ray images 50, 50' in
accordance with Figure 8, it is not possible to decide
solely from individual two-dimensional X-ray images whether
25 a drill has already punctured the cartilage layer. The
reason for this is that an X-ray image provides only a
projection of the head 70 of the femur bone 12 that, in
general, makes the circular edge of the head 70 appear
larger than it actually is.
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The method according to the invention now makes possible,
even if only two-dimensional X-ray images 50, 50' of the

femur bone 12 are available, a safe navigation of the drill
14 in such a way that the head 70, 70' of the femur bone 12
is not punctured. Using the two images 50, 50' shown in
Figure 8, a preferred direction 76, 76' in which the drill

5   14 is to penetrate the head 70 of the femur bone 12 is, on
the one hand, first characterized in each of them. On the
other hand, the semicircular outline 78, 78' of the head
70, 70', respectively, is marked manually or by means of
software for the purpose of contour extraction. In this

10   way, the projections of the geometrical structures to be
visualized are created.

Figure 9 shows how the preferred direction 76, 76' and also
a sphere corresponding to the surface of the head 70 of the

15   femur bone 12 can be visualized three-dimensionally
according to the invention using the two images 50, 50'.
This visualization proceeds correspondingly as described
above with reference to Figures 3 and 4.

20   Next, a spatial straight line 82 that corresponds to said
preferred direction is determined from the two images 50,
50' using the respective preferred direction 76, 76' drawn
in. Since the preferred direction 76, 76' marked in the two
images 50, 50' is in each case part of a straight line, the

25   two corresponding conical surfaces 40, 40' are present in
the form of a flat triangle. As is evident from Figure 9,
the spatial straight line 82 results from the spatial
intersection of the two planes defined by the conical
surfaces 40, 40'. The intersection of the two triangular

30   surfaces establishes the straight line 82, i.e. the
preferred direction, unambiguously and precisely.

As explained above, the spatial straight line 82 can be
used according to the invention intraoperatively to
navigate the drill 14. This operation is described in
greater detail below with reference to Figures 10 to 12.

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First, how the spatial arrangement of the puncture point 74
can be visualized with respect to the spatial straight line
82 is, however, explained yet again with reference to
Figures 8 and 9. For this purpose, the spatial intersection
10   is determined of those conical surfaces that each
correspond to the semicircular outline 78, 78' of the head
70 of the femur bone 12 in the images 50, 50'. As emerges
from Figure 9, the spatial intersection of the conical
surfaces corresponding to the semicircular outlines 78, 78'
15   is a visualized structure in the form of a spatial sphere
80. It should be pointed out that the position and shape of
the sphere 80 can be created unambiguously and precisely
using the semicircles (or the corresponding full circles)
78, 78'. An intersection of the sphere 80 with the spatial
20   straight line 82 yields the spatial position of the
puncture point 74.

An intraoperative visualization of the actual position of
the drill 14 relative to the puncture point 74 therefore
25   makes it possible to navigate the drill 14 in such a way
that the drilling operation can be interrupted in good time
before the puncture point 74 is reached. The visualization
of the spatial straight line 82 also makes possible a safe
navigation of the drill 14. In an intraoperative graphical
30   representation of sphere 80, straight line 82 and drill 14,
the distance between the tip of the drill 14 and the
puncture point 74 is simultaneously indicated, for example,

in numerical form. On going below a minimum distance, an
additional audible warning signal is sounded.

Of course, the spatial straight line 82 and the sphere 80
5   in accordance with Figure 9 can also be represented in the
three-dimensional graphical representations in accordance
with Figures 5 and 6 to facilitate the navigation of the
surgical instrument 14.

10   A graphical navigation aid according to the invention for a
surgical instrument by way of example for the surgical
intervention shown in Figures 7 to 9 is explained below
with reference to Figures 10 to 12. To support the
navigation of the drill 14 shown in Figure 7 in such a way
15   that it enters the head 70 of the femur bone 12 along the
spatial straight line 82 shown in Figure 9, a graphical
navigation aid is shown on the viewing screen 24 shown in
Figure 1. Said navigation aid comprises crosshairs 86 that
mark the tip of the drill 14 shown in Figure 7. The point
20   88 denotes a projection of the tip of the drill 14 on a
horizontal plane 90. The point 72 on the viewing screen 24
denotes the desired entry point of the drill 14 into the
femur bone 12. The point 72 is visualized as shown in
Figures 10 to 12 in the same way as described above with
25   reference to Figures 7 to 9 for the straight line 82 and
the sphere 80. A tunnel-type structure 92 serves as
reference point for the relative position of the spatial
straight line 82 relative to the effective axis of the
drill 14. Said effective axis extends at a right angle from
30   the position of the crosshairs 86 out of the plane of the
drawing. A projection 94 of the geometrical straight line
82 can furthermore be seen on the horizontal plane 90.

At the top right of the viewing screen 24, a direction
indicator 96 is shown. Said direction indicator 96
indicates the direction in which the tip of the drill 14
5   has to be moved in order to align the drill 14 along the
geometrical straight line 82 symbolized by the tunnel 92.
In the case shown in Figure 10, the drill 14 has to be
moved slightly downwards and relatively far to the left.
This emerges from a small arrow pointing downwards in the
10   representation field 98 and a large arrow pointing left in
the representation field 100.

Figure 11 shows the case where the drill 14, proceeding
from the position shown in Figure 10 has been moved
15   slightly downwards and slightly to the left. As is
indicated by the point in the representation field 98, the
tip of the drill 14 symbolized by the crosshairs 86 is now
situated in the same horizontal plane as the spatial
straight line 82 corresponding to the tunnel structure 92.
20   As is made clear, however, by the small arrow in the
representation field 100 pointing to the left, the drill 14
must still be moved slightly to the left in order to align
the effective axis of the drill 14 along the geometrical
straight line 82 symbolized by the tunnel 92.
25

If the drill 14 is now moved slightly to the left, the
viewing-screen content results that is shown in Figure 12.
In the direction indicator 96, two points are now shown.
This diagram indicates that the effective axis of the drill
30   14 is aligned along the preferred direction indicated by
the tunnel structure 92.

In this position, the surgeon can now switch the viewing
screen to another representation mode in order to choose,
for example, a three-dimensional visualization of a
structure to be surgically treated corresponding to the
5   viewing-screen printout in accordance with Figure 6.